

**SYSTEM CAPACITY AND ECONOMIC MODELING COMPUTER TOOL  
FOR SATELLITE MOBILE COMMUNICATIONS SYSTEMS**

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**ABSTRACT**

This paper describes a unique computer modeling tool that combines an engineering tool with a financial analysis program. The resulting combination yields a flexible economic model that can predict the cost effectiveness of various mobile systems. This model was developed by Ford Aerospace in an effort to help the world mobile community in making key decisions on the design and implementation of a Mobile Satellite Communications System. Cost modeling is necessary in order to ascertain if a given system with a finite satellite resource is capable of supporting itself financially and to determine what services can be supported. Personal computer techniques using Lotus 123 are used for the model in order to provide as universal an application as possible such that the model can be used and modified to fit many situations and conditions. The output of the engineering portion of the model consists of a channel capacity analysis, link calculations for several qualities of service using up to 16 types of earth terminal configurations. The outputs of the financial model are a revenue analysis, an income statement, and a cost model validation section. The paper will describe the Ford Aerospace model and how it is used.

## INTRODUCTION

Mobile Communications in the world community is important for thin routes where it is not economical to serve the desired coverage area with conventional terrestrial or satellite systems. These mobile satellite communications systems use low cost earth stations called transceivers which cost as low as \$2000 to \$4000 which in turn allows a large user base. These systems are used for mobile radio, mobile telephone, data services and position location. Emergency services and disaster communications round out the list of important services that are available with a mobile satellite system. Most industry analysts now predict a large pent up demand for these services. However, the market is unproven since no comparable service exists in most cases. Thus, many potential service providers are considering a pilot system for developing the service techniques and proving the market before stepping forth with an expensive dedicated system. One method for initiation of a pilot system is to place a low cost mobile satellite communications package on a host satellite that has another primary mission. Several such systems are under consideration now.

Systems are being introduced that use many types of user transceivers. These transceivers differ in performance, ranging from terminals with omni-directional antennas that are capable of only low speed data transmission, to units with directional hi-gain antennas coupled with voice codecs and data transmitters. A description of the various services and the antenna designs is beyond the scope of this paper; however, the services in Figure 1 show that there are a wide range of service needs and technical requirements. These ranges are used to model the number of channels and technical parameters that make for a cost effective system.

Cost modeling is necessary in order to ascertain if a given system with a finite satellite resource is capable of supporting itself financially and to determine what services can be supported. This paper describes a unique computer modeling tool that combines an engineering tool with a financial analysis program. The resulting technique yields a flexible economic model that can predict the cost effectiveness of various mobile satellite communications systems with differing technical parameters.

### DEDICATED SATELLITE vs. PACKAGE ON A HOST SATELLITE

A mobile satellite system package carried on a host satellite makes sense where there is no previous history of the service market. Dedicated satellite systems would cost \$160 to \$300 million launched, whereas a pilot system as a package on a host satellite could be as low as \$15 to \$30 million. Of course the system capacity is reduced as well. The mass and power required for a mobile package added to a host satellite is on the order of 70 to 80 kg and typically consumes 400 to 1000 watts DC depending on how much power is available for the mobile payload. While multiple transponders with frequency reuse could be used, the usual pilot system is a single transponder with a single beam covering the country or area of interest. The

addition of multiple transponders complicates the system from the start. The question then arises as to the economic feasibility of the usage of such a system and how many channels and users can be supported.

## BASIC PRINCIPLES OF MOBILE PILOT SYSTEM DESIGN

These pilot systems generally are downlink limited and the tradeoffs for channel capacity involve satellite DC power consumed and the management of the available power. The important parameters in the system are: The dedication of what portion of the satellite's power to the mobile system. The satellite Antenna gain, generally related to the size of the antenna to be used on the satellite. The earth station transceiver antenna gain (omni vs directional designs). Service reception characteristics related to toll quality vs. commercial quality, which are manifested in signal to noise ratios. Finally, channelization, the basic commodity that is being resourced in the system. For this analysis a 5 KHz Amplitude Companded Single Sideband (ACSB) channel is assumed for the basic quantity of resource. System tradeoffs are performed using this model. The engineering model relate these basic principles and determine the link parameters and indicate which are the most important.

## CONNECTION BETWEEN DESIGN AND ECONOMICS

Generally, the revenue that can be derived from the mobile satellite system is channel dependent and the ultimate revenue is tied to the satellite design and the mix of antennas and service quality desired on the ground. For small systems the design is limited by the downlink to the mobile user and the power in any downlink channel in such a linear system is regulated by the uplink power applied. The method used by the model to determine channel capacity is to hold the downlink margin, carrier to noise ratio, and satellite system parameters constant and vary the percentage of satellite power assigned to individual carriers that correspond to several earth station configurations and users. The resulting output of the engineering model can predict the total number of carriers that can be supported in each category of service. A financial model takes the output of the engineering model and calculates the revenue potential of the system described by the engineering model.

## MODELING TECHNIQUES

A personal computer technique was chosen to model the mobile satellite system in order to provide as universal an application as possible such that the model can be used and modified to fit many situations and conditions. Lotus 123 was chosen as the programming language since it lends itself to the financial prediction output desired and it is generally available world wide in any office situation. A simplified flow diagram of the model is shown in Figure 2. The total model was split into two sections (in order to keep the PC requirements to a minimum) that can be run independent of each other.

The model requires an IBM XT, AT, PS-2 or compatible computer and Lotus 1-2-3 Release 2.0 or higher. The model is user friendly and custom menu driven. The user must only have a rudimentary understanding of the IBM Personal Computers and Lotus 1-2-3 operations.

The models are comprised of many easy to use custom menus. Each menu consists of numerous parameters that allow user inputs such as satellite parameters, transceiver parameters, system margins, data rates etc. The link calculation formulas and calculated results are protected so they cannot be erased accidentally. In the view and print menus, the user can either view the selected service parameters on-line or obtain hard copies. Calculation and Return menus provide the means of recalculating the model according to the new inputs or returning to the previous menu. The financial model is likewise simple to use, as in the engineering model, customized menus are used for input, modification of databases and output functions. A user manual is available for both models.

## ENGINEERING MODEL

The engineering model comprises of a set of link analyses tailored to the mobile satellite service. The analyses are based upon various user input parameters, such as satellite antenna size, transponder DC power, carrier frequency, ground antenna gain, digital data rate, and end-to-end C/No. All inputs are variable and are made by responding to the computer generated prompts on display menus.

The Model can analyze multiple service quality scenarios simultaneously to calculate the transponder channel capacities. For example, both toll quality and commercial quality links can be analyzed independently. The output of the model consists of a channel capacity analysis, link calculations for two qualities of service and eight types of earth terminal configurations for each service quality. The purpose of the output is to display the channel capacity of a specific satellite configuration from the perspective of a satellite system operator.

## ENGINEERING PRINCIPLES AND ASSUMPTIONS

The satellite transponder is assumed to be occupied with many narrow bandwidth SCPC carriers. They are spaced uniformly across the band on 5 KHz centers. The carriers are either Amplitude Companded Single Sideband voice (ACSB) or GMSK digital traffic. GMSK has a band width equal or less than the ACSB voice channels. It is assumed that at any given time, only a fraction of the total channel capacity (in terms of number of channels) is transmitting. That is, a VOX activity factor of 4 db (also variable) is used in the link calculations.

The engineering model is developed based upon the following link calculations: First the transponder Effective Isotropic Radiated Power (EIRP) is calculated based upon transponder RF power, antenna gain and output losses. Next, the clear sky Carrier to Noise Ratio (C/No) is obtained based upon the required end-

to-end C/No (service quality can be expressed in terms of end-to-end C/No), Carrier to interference ratio (C/Io), loss margins, and uplink C/No. After the C/No is calculated a beam center EIRP is obtained. The Beam center EIRP per carrier is based upon ground antenna gain, system temperature, free space loss, an activity factor (VOX) and Boltzman's constant. Finally, the transponder capacity can be calculated in terms of number of channels from the known transponder EIRP and beam center EIRP.

## FINANCIAL MODEL

The Financial Model uses the output cases from the engineering model to convert numbers of channels to air time revenue. The program generates air time revenue based upon several user defined parameters. The major variables that determine the revenue formulas are price per minute, demand over the life of the program and average daily utilization. The outputs of the model are a revenue analysis, an income statement, and a cost model validation section.

## MODEL INPUTS & OUTPUTS

The input to the model are price, program demand, daily utilization, capital cost, cost of capital, and tax calculations. For preliminary system design analysis the program is loaded with united states market and tax parameters with a 14% cost of capital, however, the model is easily modified for other countries or situations. The output reports are hard copy detailed revenue statement for each service and an income statement for the project.

## FINANCIAL PRINCIPLES AND ASSUMPTIONS

The method of charging the user for the use of the satellite resource is to obtain the cost of the users' portion of the satellite resource. Since the portion of the satellite resource used is relative to the downlink power used in order to meet a certain service quality, all users can be related in price to a standard (such as a user with an Omni-directional antenna transceiver, requiring voice service with toll quality). The cost of other services then are determined in some proportion to the standard. All services are capable of being varied in cost. Furthermore, certain users may want to use higher data rates and/or different modulation techniques than the standard 5 Khz ACSB modulation of the standard. The model can handle these variations and the model user has complete control to vary the use of the channels. Surcharges for multiple contiguous channel usage are allowed.

The model is completely flexible in determining the usage of the transponder. For example, Figure 3 shows that the rate of customer loading can be controlled for each quality of service. Daily transponder usage modeling is available for both weekday and weekend/holiday periods. Easy modification of the curves allow the model user to see the effect of time zones and system user demographics. The model also allows the user to input system start up costs (such as satellite costs, master

earth station(s), Demand Assignment Multiple Access controllers, office space and anything else the user wants to include. Depreciation, tax data, and the time value of money over the life of the program is included.

Present value formulas for uneven cash flows that are dependent on system usage are calculated on an annual basis and summed to achieve a Net Present Value (NPV) for the project. Internal Rate of Return (IRR) is also calculated.

## FINANCIAL MODEL RESULTS

After a financial analysis of a case is calculated the results are displayed graphically using the present value of the cash flows of the project. The graph displayed shows the time adjusted sunk cost and break-even analysis for the project. Figure 4 is a simplified sample graph that would be displayed on the screen. The financial analysis is then checked against the average capacity of the basic system. A validation section is provided as a tool by which to check the average number of users the system can support. The parameters of the average user for each category of service can be varied and used to calculate the number of users the system can support on an average business or weekend day and the cost to these typical users per month. A balance between market mix and financial return can be displayed for a total system analysis for each engineering case.

## CONCLUSION

This model can be used to predict the financial viability of simple, low cost mobile communications systems. The resulting calculations can be plotted against each other to show which systems are capable of sustaining themselves. An example of this process is shown in figure 5. In this simple example the model was run with various DC power levels on the satellite. The number of channels supported is then plotted against the DC power and the limits imposed by bandwidth availability, DC power availability, and link performance are established by model output. Financial viability can then be shown as the systems that fall within the surrounding "box". Shown in this simple example, System 1 with Hi-Gain antennas is financially viable while System 2 with Omni antennas would not be, even though a certain number of channels could be supported technically.

SERVICES	MOBILE ANTENNA TYPE						
	Gain	OMNI		HI-GAIN		PORTABLE	
	Quality	Toll	Comcl	Toll	Comcl	Toll	Comcl
Land Mobile Telephone							
Land Mobile Radio/Paging							
Air Mobile Telephone							
Air Mobile Radio							
Position Location Services							
Public Safety/Medical							
Public Utilities							
Resource Extraction							
Rural Telephone							
Interactive Data							
Construction/Agriculture							
Coastal Marine							
Rail							
Government Agencies							

OMNI = 5 - 7 dbi  
 HI-GAIN = 10 - 15 dbi  
 PORTABLE = 20 - 22 dbi

Toll Quality = 47 DB - Hz  
 Commercial = 43 DB - Hz

Figure 1. Definition of Service Categories

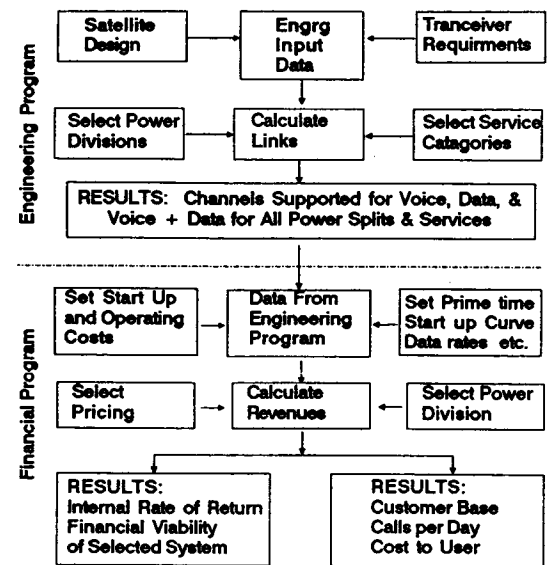


Figure 2. Model Flow Diagram

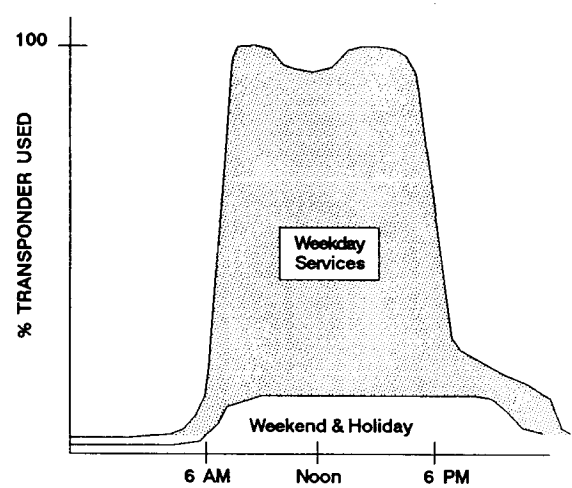
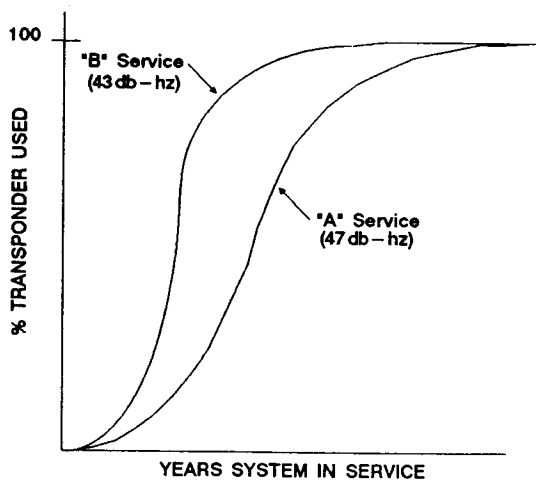


Figure 3. Transponder Usage Variables

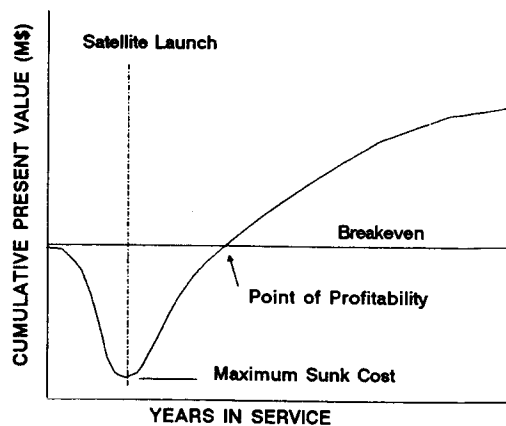


Figure 4. Example Cash Flow Analysis

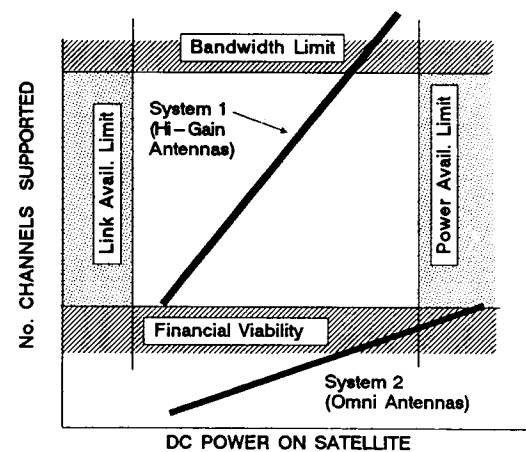


Figure 5. Example Tradeoff